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Review study on variables for performance improvement of BF_3 combination detector

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1. Introduction

Neutron never ionize atom directly, therefore, indirect detecting method of unionized atom is used. Neutron detector uses reaction between neutron and materials. When neutron approaches some nucleus of atoms, nuclear reaction happens and produces charged particles or photons. These charged particles or photons are measured by neutron detector.

Nuclear reaction of neutron largely depends on neutron velocity, energy of neutron. Therefore, different detectors are applied to measure it. Among them, BF_3 detector which is one of gas proportional counter uses (n, α) reaction as a nuclear reaction. BF_3 detector is easy to distinguish gamma ray, it also has long lifetime, low radiation damage compared to other detectors. B^{10} component in filled gas reacts with neutron, it converts neutron to charged particle, ^{4}He(α particle) and ^{7}Li, they are measured in proportional counter. Using this detector, this is used to detect thermal neutrons from nuclear reaction or fast neutron from recoil interactions. Also, this detector is relatively stable and efficient.

In this study, variables for performance improvement of BF_3 combination detector with low sensitivity detector and high sensitivity detector are examined. Through viewed variables, variable control experiment for performance improvement of BF_3 combination detector will be conducted. Using information about performance improvement of BF_3 combination detector, especially detection efficiency of neutron will be accomplished.

2. Variables Affecting Performance Improvement

There are various reactions used in detection of neutron. Generally, detection of fast neutron uses endothermic reaction and detection of thermal neutron uses exothermic reaction. Among them, BF_3 proportional counter tube uses reaction of $^{10}B(n,\alpha)^7Li$ reaction, it has large reaction cross section and high sensitivity to thermal neutron because the reaction is exothermal reaction. BF_3 detector is usually used to detection of neutron, especially thermal neutron. However, neutrons from ^{241}Am-Be source are fast neutrons, therefore, thermal neutron is detected by slowing down of fast neutron using paraffin [1]. Full neutron energy is not deposited in detector because recoil type counter only measures first interaction neutron. Therefore, neutron detector only measures the number of neutrons, but, not about their full energy. Experiment variables affecting performance improvement of BF_3 combination detector was analyzed to improve performance of BF_3 neutron detector, they are shield control to neutron backscattering, BF_3 tube pressure, temperature, cross section, detector assembly as seen in Fig. 1.

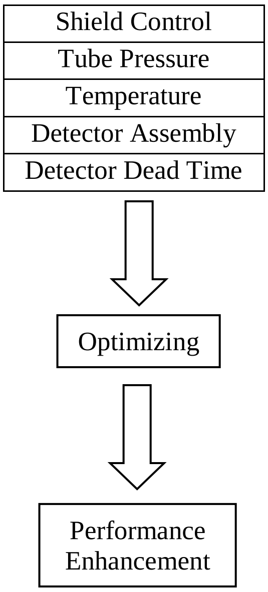

Fig. 1. Schematic diagram of variables for performance improvement of BF_3 combination detector

2.1 Shield Control to Neutron Backscattering

Neutron backscattering (also called neutron moderation) was investigated in 1953 by Stanford Research Institute. This way uses the moderation of fast neutrons by hydrogen nucleus. Interaction of fast neutrons decreases with amount of hydrogen in material because fast neutron is absorbed in hydrogen, therefore, it is understood that a little neutron back scattered from hydrogenous material are fast neutrons. BF_3 tube used in experiments has 28 cm length and 2.54 cm diameter, it was operated at 2000 V [1]. Suitable shield for BF_3 detector is a combination of both boric acid and graphite. Am-Be neutron source has 5 Ci intensity and a wooden box, 60×60×100 cm^3 were used in experiments [1]. But, shield used to surround detector and neutron source functions important variable to scatter neutrons into detector and boric acid absorbs backscattered thermal neutron by role of ^{10}B in structure. By graphite shield, neutrons from source are moderated and reflected, thermal neutron flux is increased in detector. Also, shield blocks source neutron approaching detector by scattering or absorption. Shielding material absorbs external neutrons come from source and reflects backscattered thermal neutrons approaching to detector.

Because neutron induced reaction is limited, energy information acquisition in neutron detection system is hard. Only first interaction of neutron is measured by recoil-type counter, therefore, entire neutron energy is not deposited in detector. Only information to number of neutron could be obtained, but, information about their energy is not obtained. Thus, kind of shield could influence performance of detector by process of moderation or reflection or flux control or scattering and absorption block. As you see in Fig. 2, relative count difference variation with/without PE sample (=contrast: value of contrast is calculated by equation $[(N-N_0)/N_0] \times 100$ (%). Here, N stands for neutron count with PE sample, N_0 stands for neutron count without PE sample, PE sample plays a role of moderator, therefore, N is larger than N_0 because more thermal neutron is produced by hydrogen in PE sample) depending on shield material either only graphite or graphite + boric acid is shown in Fig. 2.

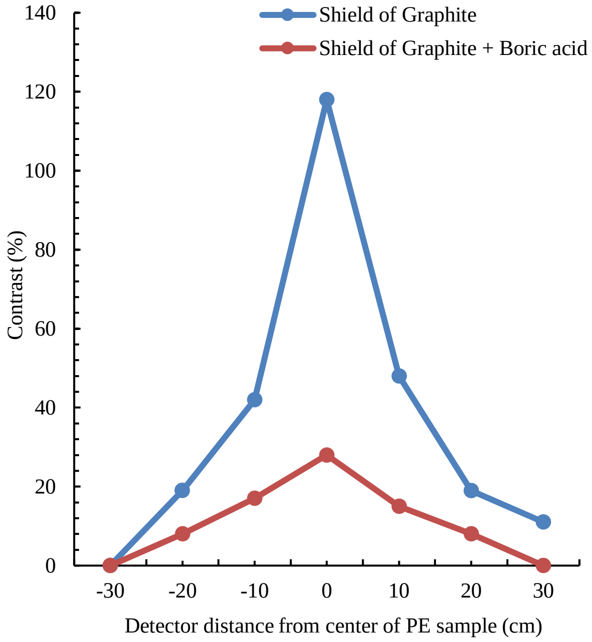

Fig. 2. Variation of contrast versus distance from PE sample buried in soil 3 cm deep [1]

2.2 BF_3 Tube Pressure

Boron trifluoride gas has properties such as corrosiveness, low neutron cross-section and higher operation voltage requirement. As increasing tube pressure, efficiency of BF_3 tubes increases, however, needed operating voltage also increases [2]. Because high voltage could make break down, many number of lower pressure tube to decrease needed voltage and to maintain neutron efficiency are preferred option for BF_3 proportional counters. Depending on different BF_3 pressure and numbers of tubes, system efficiency change could be investigated. Already, Pacific Northwest National Laboratory (PNNL) measures neutron detection efficiency of BF_3 tubes by change of tube pressure. However, increase of efficiency was not linear with pressure of tube, it is likely due to difference of electronics used, also, tubes shielding each other and space constraints of moderating box are another variable of efficiency. Measurements were obtained in condition of ^{252}Cf neutron source, source activity was 21.5±1.23 μCi [2]. Four 107, 120 kPa BF_3 tube were modeled, as a pressure of BF_3 tube is increasing and number of tubes is increasing, neutron detection efficiency is also increasing [2]. In case of 4 BF_3 tubes, efficiency of BF_3 tube changes from 1.6 cps/ng in 107 kPa to 3.7 cps/ng in 120 kPa [2]. Neutron detection efficiency of one tube and two tubes as a function of tube pressure was predicted by Eq. (1),(2) [2].

$$E = 0.90\ln(P)-2.39 \quad (1)$$
$$E = 1.15\ln(P)-2.43 \quad (2)$$

where E is efficiency (cps/ng ^{252}Cf) and P is the pressure (kPa). Experimental efficiency was 11% higher than model prediction [2]. Size of moderating box prevents tube from shielding each other. Optimizing moderating box could be predicted to increase neutron detection efficiency of BF_3 tube. This performed study suggests space restraint of moderating box could make improvement in neutron detection efficiency.

The uncertainty in experimental results was due to uncertainty in source strength. The statistical uncertainty of results was less than 2% [2].

The efficiency in counts per emitted neutron was obtained using conversion factor 2.3×10^4 n/s [2]. BF_3 counter is sensitive to neutron absorption cross section. If the yield of neutron source or length of counting time is not limited, use of BF_3 counter with low gas filled pressure has advantage because the highest precision of cross-section determination could be attained [3]. Thus, efficiency of BF_3 tube is proportional to tube pressure and needed operating voltage, but high operating voltage could make problem. That's why several lower pressure tube settings could be good alternative to maintain neutron efficiency. The fact that pressure and numbers of tubes are variables of influencing efficiency of detector was investigated.

Table I: BF_3 tube pressures and configurations tested and the corresponding neutron detection efficiencies (cps/ng ^{252}Cf) [2]

Pressure (kPa)	Number of tubes	Theoretical efficiency	Experimental efficiency
107	1	1.49	1.62
107	2	2.27	2.67
107	3	2.86	3.27
107	4	3.26	3.75
120	1	1.58	1.58
120	2	2.38	2.59
120	3	3.00	3.04
120	4	3.41	3.38

2.3 Temperature

In case of one of two detectors, full energy peak of $^{10}B(n,\alpha)^{7}Li$ reaction could be checked only near room temperature and gas multiplication is inversely proportional to temperature. The other detector didn't show full energy peak on pulse-height distribution at room temperature, but full energy peak appeared at sub-zero temperature. As detector temperature decreased, peak became sharp. These results are caused by structure of suspender supporting an anode and impurities in enclosing gas each other. Temperature dependence data of BF_3 detector is needed to reactor instrument for fuel failure detection system. Temperature in this experiment ranges from -70 ℃ to 70 ℃ [4]. Change of pulse height distributions for counter is caused by impurities in filling gas. Temperature of detector was controlled by electric heater when it heats over room temperature, on the other hand, when it cools below room temperature, liquid nitrogen was used to make it. Adjustment of detector temperature was controlled by changing heater current and rotation speed of fan. Neutron source used in experiment was 1 μg ^{252}Cf. It was set in polyethylene block [4]. The distance between source and anode wire of detector is approximately 20 cm [4]. Detector related to preamplifier to spectroscopy amplifier, ORTEC model 142 PC and 572 respectively [4]. Output signal of amplifier is transferred to MCA-8000, detector bias was supplied by high voltage power supply, NAIG E-503 through a high voltage buffer [4]. Pulse of precision pulse generator was transferred to 'test-input' of preamplifier to assure reliability of measuring system. As temperature is decreasing, pulse-height (channels) is also decreasing. By changing temperatures, change of pulse-height distributions is checked. Full energy peak is appeared in pulse height distributions at temperatures of -41 and -75 ℃ [4]. Peak width of pulse height distribution becomes wider as temperature of detector is distinguished from room temperature and pulse height increases when temperature decreases. The cause of temperature dependence for counter is estimated by peculiarity of anode and cathode. By change of temperature, gas multiplication and energy peak on pulse height are also influenced. Temperature is controlled by electric heater and liquid nitrogen gas, settings in experiment is also arranged. Pulse height change and energy peak could be checked by temperature.

2.4 Detector Assembly

Design of large oil-moderated BF_3 assembly for photo neutron is studied. Detector shows high neutron detection efficiency which is independent of neutron energy and it corresponds with design prediction. Detector assembly set as 4π solid angle about neutron emitting sample [5]. This assemble makes required high efficiency and separation of neutron pulse in time. Suitable detector geometric arrangement in moderator could attain detector efficiency. BF_3 detector is proper to pulsed measurements.

Large oil-moderated detector containing ringed arrays of BF_3 counters was built. Improvement in reducing energy dependence of detector efficiency and data processing was made. Fast neutrons are thermalized in hydrogenous moderator in several microseconds and thermalized neutrons are disappearing exponentially with time because neutrons are either captured or leak from detector. The mean life-time of thermalized neutron is between 30 and 140 μs, BF_3 proportional counter was chosen because it has advantage of distinction about inherent lower sensitivity to gamma-rays [5].

Configuration was set by 56 BF_3 detectors arranged in 5 cylindrically symmetric rings containing 8,8,8, 16 and 16 detectors at mean radii of 88.9, 152.4, 190.5, 248.9, 306.1 mm [5]. They are copper walled, 50 mm in diameter, with active length of 1070 mm filled to pressure of 700 mmHg with BF_3 enriched to 96% in ^{10}B [5]. Aluminum tube has outside diameter 95 mm wall thickness 1.5 mm, coaxial with counter rings and center of detector is entrance and exit of photon beam [5].

The choice of oil instead of polythene for moderator has advantage of free and easy transformable geometry. Detector was shielded by 50 mm of lead, 1.5 mm of cadmium, 150 mm of borated resin [5]. Side facing incident photon beam where lead shielding is reinforced to 100 mm [5]. Electronics take signals from detector about multiplicity of each event, information on average neutron energy of source. Ring ratio (defined as ratio of count rate in outermost to innermost rings) yields average neutron energy of source and it also enables necessary correction to detector efficiency. Neutron efficiency of detector assembly as a function of neutron energy was measured using ^{241}Am-Li, -F, -B, -Be sources [5].

Efficiency drops by 7% from 0.45 to 4.2 MeV neutron energy in good agreement with design calculation [5]. Insensitivity of detector efficiency to source position was studied using Am-Li source. Source was moved along the symmetry axis of detector, within statistical accuracy of 0.25% [5]. No change in efficiency was recorded for displacements up to 150 mm from center position [5]. Vertical displacements of source at the center showed no statistically significant difference. These observations show shorter BF_3 detector could have advantage of reduced background.

2.5 Detector Resolution and Dead Time

The most important thing of BF_3 detector is not good pulse height resolution which provides that signal could be well separated from noise, but minimum resolving time between pulses at discriminator. Good resolution and short dead times are conflicting properties and compromise between them is essential.

Differentiation time constant is 1 μs on pre-amplifier and differentiation and integration time constants are 1 μs and 0.5 μs each other for main amplifier [5]. Under these conditions, dead time of ring 1 is 2.1±0.1 μs and resolutions of other rings were better, but dead times were similar as 0.07 μs [5]. Dead time and delay to display time separations between the pulse and all other pulses were measured directly using time to amplitude converter [6]. Effective dead time of system is reduced below 2.1 μs by independent processing of 5 rings and count rate was very insensitive to variation of discriminator threshold, 10% variation in threshold produces less than 0.5% variation in count rate [5].

3. Conclusions

In this study, variables affecting performance of BF_3 neutron combination detector was suggested. Various variables including shield control to neutron backscattering, tube pressure, temperature, detector assembly are analyzed. From further study on neutron detector, neutron detection performance limitation by variables such as shield control to neutron backscattering, BF_3 tube pressure, temperature, cross section, detector assembly would get more clearly and systematically solved.

In this study, the fact that kind of shield could influence process of moderation or reflection of neutron or flux control or scattering and absorption block was checked. Also, the fact that pressure of tubes and number of tubes are directly connected to efficiency of detector could be checked. Temperature change of detector could change energy peak and pulse height distribution. Detector assembly, geometric arrangement and resolution of detector and dead time settings are another variables to change efficiency of detector and influence performance of detector.

Utilizing these information, experiment design for detector performance improvement and investigation about efficiency improvement of combination detector would be accomplished. Ultimately, composition and development for enhanced accuracy of neutron detector are our next goal.

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